Practical Considerations When Using Commercial Robotic Arms for Antenna Metrology

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***Abstract* – The National Institute of Standards and Technology has been using commercial robotic arms to characterize antenna gain and radiation patterns. The transition from custom antenna hardware to commercial robotics has opened up new capabilities but has also highlighted some issues that need to be addressed to ensure full confidence when using these systems.**

***Index Terms* — Antennas, Calibration, Gain, Metrology, Near-Field, Pattern, Robotics.**

1. Introduction

The use of commercial robotics for measuring radio-frequency (RF) to milli-meter wave (mmWave) emissions and patterns is starting to leave research testbeds and entering main stream antenna testing [1]-[4]. There have been multiple groups measuring antenna performance, and characterizing the suitability and ease-of-use of coordinated-motion robotics for antenna measurements, see Fig.1 [3]-[8]. Antenna measurements up to 330 GHz have been reported, Fig. 2 [6], robot-mounted integrated sensor suites, which measure more than just antenna performance, have been demonstrated up to 18 GHz using a low-cost arm [7], and suitability for scanning geometries up to 500 GHz has been proposed when combined with external spatial metrology [3].

As more systems are being demonstrated, there is greater scrutiny being paid to performance, speed, safety, and general operability with other equipment. Individual design requirements show differences in optimized features, e.g., implementations that require a high degree of spatial knowledge to limit uncertainties in low signal-to-noise (SNR) parts of the pattern, may use spatial metrology to infer antenna positions at varying cost and complexity while systems that are optimized for throughput or lower frequency operation forgo these additional costs [8].

2. Design Considerations When Using Commercial Robotic Arms

Compared to traditional stacked-stage antenna measurement systems of approximately similar scan size, commercial serial-robotic arms on the surface can seem to have larger positioning errors which could limit their usability for antenna measurements, especially at mm-Wave frequencies [8]. Most commercial robotic arm systems are designed to operate in arbitrary poses over large volumes, moving large payloads at high speed in continuous operation and doing these tasks *repeatably*. In our case, accuracy is

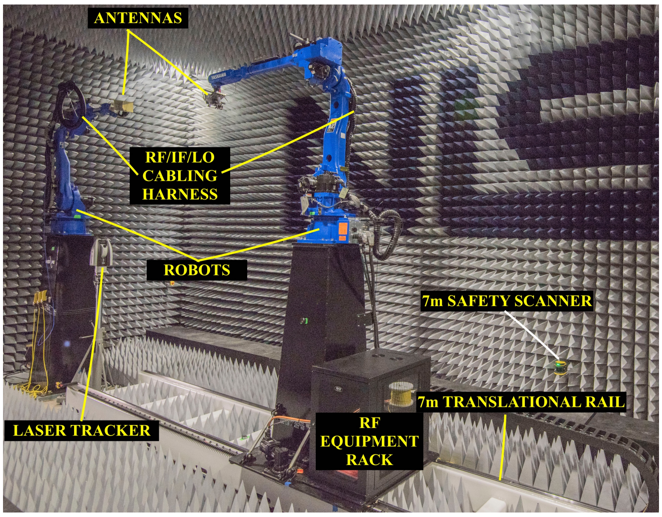

Fig. 1. The Dual-Arm Large Antenna-Positioning System at NIST.

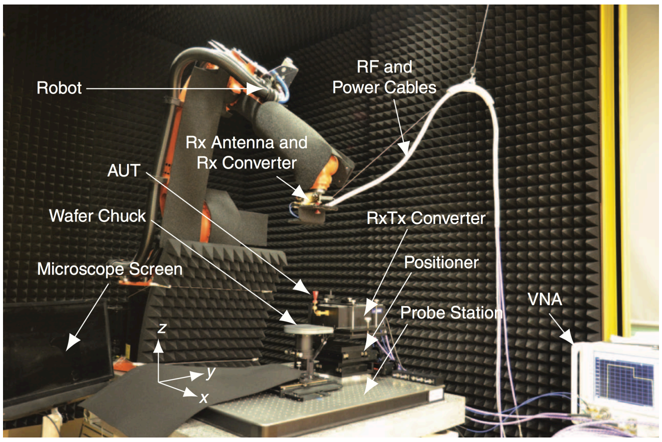

Fig. 2. A robotic arm antenna system with absorber treatment at ULM University [6] (Photo courtesy of ULM University, Germany).

typically more important than speed, so we need to assess how to properly utilize robots for antenna measurements.

Some of the factors that affect antenna performance results include: antenna and probe positioning *accuracy* and mechanical repeatability, signal repeatability, scan volume, and coordination with other pieces of equipment (for example, the robot, RF and spatial measurement equipment).

(1) Accuracy and repeatability

Antenna ranges can use errors in probe position relative to the antenna under test (AUT) to assess gain and pattern uncertainty. A rule of thumb is that for a 20 dBi gain antenna, to achieve a noise level due to positioning errors of -50 dB, a position accuracy of $\lambda/50$ is required (where λ is the operating wavelength). Accuracy can be described as the average difference between a desired and actual probe to AUT position. Repeatability is the deviation of the accuracy over time. Robotic arms usually generate position using a variation of a serial Denavit-Hartenburg (DH) model [9]. The repeatability of a robot is determined by the quality of the motors and gearing. The accuracy is determined by the knowledge of the DH model. This model can be better determined by using spatial metrology tools to improve overall accuracy [10].

(2) Spatial Metrology – Path vs DH Calibration

Spatial metrology, determining AUT and probe location and orientation, can be costly in terms of budget, development, and measurement time. Laser trackers and laser radars can cost more than the 3 to 4 m reach robotic arm they are measuring, while photogrammetry systems can take longer to process and have limited spatial accuracy.

Using in-the-loop position metrology, basic path geometry can be corrected to the level of the robot or metrology resolution [3]. A less costly alternative can be to calibrate the DH model for a range of robot loads. This gives a calibration to the level of robot repeatability or motor backlash performance over a full volume rather than a specific path [11].

(3) Robot to Process Synchronization

In order to perform antenna measurements, synchronization between the robot and an RF measurement is required. The easiest, but slowest, method for doing this is to stop the robot at each point. Taking data as the robot moves or “on-the-fly” requires synchronization between all components, especially robot positioning and event triggering. Traditional near-field ranges can typically trigger more accurately in time than commerical robots. However if position is known, even if there is an error, accurate patterns can still be determined [12].

(4) RF and mmWave Signal Stability

As the operational frequency increases, the signal stability with movement tends to worsen [3],[6]. Using mixer-based systems to convert frequency, attenuation changes can be lessened. However, the phase variations can be augmented, as they scale with the multiplication order. Modern phased arrays can use 5 to 8 bit phase shifters, so to ensure proper testing of these systems, phase errors due to movement need to be kept to within 2^{-5} (11.25°) to 2^{-8} (1.5°)

The use of cable service loops to limit differential bending, Fig. 2, can be effective in limiting phase changes. Most industrial robotic arms have defined cable routing for control signals which are designed to provide a minimal stress to these cables to ensure longevity. By using this path for RF cabling, stress and phase change from the cables are minimized, Fig. 1.

3. Dynamic Measurements

New communication and phased array systems, especially systems that are expected use digital beamforming, will no longer have the ability to directly test the antenna [13]; furthermore, static tests will not suffice to exercise these systems. The ability to rapidly and arbitrarily move to a point and capture data is a task more suited for robots. Additionally, multiple robots can interrogate systems in concert or independently, providing additional over-the-air testing capabilities, see Fig. 1.

4. Conclusion

Multiple groups have shown the basic capability of robotic arms to perform antenna measurements at RF to mmWave frequencies. To achieve pattern and gain accuracies in a time frame commensurate with traditional near-field ranges, a robust analysis of system timing and position can greatly improve results. Furthermore, full six degree-of-freedom positioning capability can perform several scan geometries, dynamic measurements, and improve final pattern and gain results by actively correcting to the resolution of the robot.

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